Climate Change Effects and Adaptation Approaches in Freshwater Aquatic and Riparian Ecosystems in the North Pacific Landscape Conservation Cooperative Region

A Compilation of Scientific Literature

Phase 1 Draft Final Report

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EXECUTIVE SUMMARY

This Phase 1 draft final report provides a first-ever compilation of what is known—and not known—about climate change effects on freshwater aquatic and riparian ecosystems in the geographic extent of the North Pacific Landscape Conservation Cooperative (NPLCC). The U.S. Fish and Wildlife Service funded this report to help inform members of the newly established NPLCC as they assess priorities and begin operations. Production of this report was guided by University of Washington's Climate Impacts Group and information was drawn from more than 250 documents and more than 100 interviews. A final report will be published in 2012 following convening of expert focus groups under Phase II of this project.

Information in this report focuses on the NPLCC region, which extends from Kenai Peninsula in southcentral Alaska to Bodega Bay in northwestern California, west of the Cascade Mountain Range and Coast Mountains. The extent of the NPLCC reaches inland up to 150 miles (~240 km) and thus only includes the lower extent of most large watersheds. This area is home to iconic salmon, productive river, lake, and wetland systems, and a wide variety of fish, wildlife, amphibians, and other organisms. Many of these species, habitats, and ecosystems are already experiencing the effects of a changing climate.

Carbon Dioxide Concentrations, Temperature, and Precipitation

Increased atmospheric carbon dioxide (CO_2) contributes to the earth's greenhouse effect, leading to increased air temperature, altered precipitation patterns, and consequent effects for biophysical processes, ecosystems, and species.

- **Atmospheric CO_2 concentrations have increased** to ~392 parts per million (ppm)[1] from the pre-industrial value of 278 ppm,[2] higher than any level in the past 650,000 years.[3] By 2100, CO_2 concentrations are projected to exceed ~600 ppm and may exceed 1000 ppm.[4]
- **Annual average temperatures have increased** ~1-2°F (~0.56-1.1°C) from coastal British Columbia to northwestern California over the 20th century[5] and 3.4°F (~1.9°C) in Alaska from 1949 to 2009.[6] Winter temperatures increased most: 6.2°F (3.4°C) in Alaska[7] and ranging from 1.8 to 3.3°F (1.0-1.83°C) in the remainder of the region.[8] By 2100, the range of projected annual increases varies from 2.7 to 13°F (1.5-7.2°C), with the largest increases projected in Alaska.[9] Seasonally, winter temperatures will continue to warm most in Alaska,[10] while summers are projected to warm most in the remainder of the region (2.7-9.0°F, 1.5-5.0°C).[11] These changes are projected to reduce snowpack[12] and summer streamflow,[13] increase water temperature, [14] and will likely lead to increasing physiological stress on temperature-sensitive species,[15] drying of alpine ponds and wetlands, and reduced habitat quality for dependent reptiles and amphibians.[16]
- **Seasonal precipitation varies but is generally wetter in winter.** Cool season precipitation (Oct-March) increased 2.17 inches (5.51 cm) in Alaska from the periods 1971-2000 to 1981-2010.[17] In Washington and Oregon, winter precipitation (Jan-March) increased 2.47 inches (6.27 cm) from 1920 to 2000.[18] In California, winter precipitation increased between 1925 and 2008,[19] while in British Columbia, both increases and decreases in winter precipitation were observed, depending on the time period studied.[20] Increased cool season precipitation raised winter flood risk in much of the Puget Sound basin and coastal areas of Washington, Oregon, and California.[21] Over the 21st Century, winter and fall precipitation is projected to increase 6 to 11% in BC and 8% in

Washington and Oregon, while summer precipitation is projected to decrease (-8 to -13% in BC and -14% in WA and OR).[22] In southeast Alaska, however, warm season precipitation is projected to increase 5.7%.[23] These changes have implications for future patterns of winter flooding and summer low flows and will affect the water quality and supply that freshwater species rely upon.[24]

Impacts of climate change on freshwater aquatic and riparian systems

Increases in CO_2 and air temperature, combined with changing precipitation patterns, are already altering numerous conditions, processes, and interactions in freshwater aquatic and riparian ecosystems. In most cases, these trends are projected to continue.

- **Reduced snowfall and snowpack, especially at lower and mid elevations:** In Juneau (AK), winter snowfall decreased ~15%, or nearly 1.5 feet (~0.45 m) between 1943 and 2005.[25] In the Cascade Mountains, April 1 snow water equivalent (SWE) has declined 16%[26] to 25%[27] since 1930. And in the lower Klamath Basin (CA), April 1 SWE decreased significantly at most monitoring sites lower than 5,905 feet (1,800 m) but increased slightly at higher elevations.[28] By 2059, April 1 SWE is projected to decline from 28%[29] up to 46%[30] in the NPLCC region. A 73% decline in snow accumulation is projected for California's North Coast under a doubling of atmospheric CO_2 concentrations.[31] For all but the highest elevation basins, loss of winter snowpack is projected to result in reduced summer streamflow, transforming many perennial streams into intermittent streams and reducing available habitat for fish, amphibians, and invertebrates dependent on constant flow and associated wetland conditions.[32]
- **Earlier spring runoff:** In the NPLCC region, the timing of the center of mass of annual streamflow (CT) shifted one to four weeks earlier and snow began to melt approximately 10 to 30 days earlier from 1948 to 2002.[33] From 1995 to 2099, CT is projected to shift 30 to 40 days earlier in Washington, Oregon and Northern California and 10 to 20 days earlier in Alaska and western Canada.[34] Both the spring freshet and spring peak flows are projected to occur earlier for basins currently dominated by glaciers, snow, or a mix of rain and snow.[35] In currently rain-dominant basins, runoff patterns will likely mimic projected precipitation changes.[36] In snowmelt-dominant streams where the seaward migration of Pacific salmon has evolved to match the timing of peak snowmelt flows, reductions in springtime snowmelt may negatively impact the success of smolt migrations.[37]
- **Increased winter streamflow and flooding:** In six glaciated basins in the North Cascades, mean winter streamflow (Nov-March) increased 13.8% from 1963 to 2003.[38] Winter streamflow also increased in non-rain-dominated basins in British Columbia and the Pacific Northwest from 1956 to 2006.[39] In the western U.S. from ~1975 to 2003, flood risk increased in rain-dominant and particularly in warmer mixed rain-snow-dominant basins, and probably remained unchanged in many snowmelt- and cooler mixed-rain-snow-dominant basins in the interior.[40] Under a warmer future climate with increased rainfall and decreased snowfall, winter streamflow and flood risk will increase, particularly for mixed rain-snow basins in the region.[41] At Ross Dam on the Skagit River (WA), the magnitude of 50-year-return flood events is projected to increase 15% by the 2040s (compared to 1916-2006).[42] The egg-to-fry survival rates for pink, chum, sockeye, Chinook, and coho salmon will be negatively impacted as more intense and frequent winter floods wash away the gravel beds salmon use as nesting sites.[43]

- **Decreased summer streamflow:** In the Pacific Northwest, northwestern California, and coastal British Columbia, those watersheds receiving some winter precipitation as snow experienced a decrease in summer streamflow from 3% to more than 40% between 1942 and 2006.[44] By 2100, further declines in the number and magnitude of summer low flow days are projected throughout the region.[45] In Washington's rain- and mixed rain-snow basins, the 7-day low flow magnitude is projected to decline by up to 50% by the 2080s.[46] Projected declines in summer streamflow will reduce the capacity of freshwater to dilute pollutants.[47] Combined with increased summer stream temperature, this will reduce habitat quality and quantity for stream-type Chinook and coho salmon, steelhead, and other freshwater fishes.[48]

- **Reduced glacier size and abundance in most of the region:** Fifty-three glaciers have disappeared in the North Cascades since the 1950s,[49] glaciers in the Oregon Cascades lost 40% to 60% of their area from 1901 to 2001,[50] and the Lemon Glacier near Juneau (AK) retreated more than 2600 feet (792 m) from 1953 to 1998.[51] However, in California, Mt. Shasta's glaciers exhibited terminal advance and little change in ice volume, as increased temperatures were counteracted by increased winter snow accumulation.[52] Limited projections for the 21st century indicate glacial area losses of 30% to 75% in parts of the NPLCC region.[53] The Hotlum glacier on Mt. Shasta is projected to disappear by 2065.[54] Where the contribution of glacial meltwater to streamflow is reduced or eliminated, the frequency and duration of low flow days is projected to increase,[55] raising stream temperature and suspended sediment concentrations and altering water chemistry.[56]

- **Increased water temperature:** Observed increases in lake and river temperatures are generally projected to continue, exceeding the threshold for salmon survival in some areas of the NPLCC region. Annual average water temperature in Lake Washington increased ~1.6°F (0.9°C) from 1964 to 1998.[57] In Johnson Creek (OR) water temperature variability increased over a recent 10-year period, suggesting that stream temperatures frequently exceed the local threshold level of 64.4°F (18°C).[58] In western Washington, simulations of maximum August stream temperatures from 1970 to 1999 showed most stations remained below 68°F (20°C), the upper threshold for salmon survival.[59] However, in the 21st century, a prolonged duration of water temperatures beyond the thermal maximum for salmon is projected for the Fraser River (BC),[60] the Lake Washington/Lake Union ship canal (WA), the Stillaguamish River (WA),[61] and the Tualatin River (OR).[62] In Washington by the 2080s, stream temperatures are projected to increase by 3.6 to 9°F (2-5°C).[63]

- **Changes in water quality:** Documented effects of climate change on water quality were not found, and water quality projections are both limited and widely varying for the NPLCC region. In seasons and areas where increased flows are projected, nutrient contaminants may be diluted (e.g. northwest BC)[64] or alternatively, sediment nutrient loads may be increased (e.g. during winter in the Tualatin Basin, OR).[65] Projected declines in summer flows and water supply may decrease nutrient sediment loads, but projected increases in development or other stressors may counteract the decline.[66] Lakes may experience a longer stratification period in summer[67] which could enhance eutrophication and lead to oxygen depletion in deep zones during summer, eliminating refuges for coldwater-adapted fish species.[68] In coastal areas, saltwater intrusion due to sea level rise was observed in Island County (WA)[69] and is projected to increase in the neighboring Gulf Islands (BC),[70] as well as other areas where coastal water tables are influenced by marine systems.[71]

- **Reduced seasonal ice cover:** The spatial and seasonal extent of ice cover on lakes will be reduced due to climate change.[72] For example, in several British Columbia lakes, the duration of ice cover decreased by up to 48 days over the 1976 to 2005 period.[73] For mid-latitude lakes, each 1.8°F (1°C) increase in mean autumn temperature leads to a 4 to 5 day delay in ice freeze-up, while the same increase in mean spring temperature leads to a 4 to 5 day advance in the onset of ice break-up.[74] Community and invasion processes may be affected as reduced ice cover increases light levels for aquatic plants, reduces the occurrence of low oxygen conditions in winter, and exposes aquatic organisms to longer periods of predation from terrestrial predators.[75] In northern regions where productivity is limited by ice cover and/or temperature, productivity may increase, providing additional food for fish and other species.[76]

Implications for ecosystems, habitats, and species

Climate-induced changes in air temperature, precipitation, and other stressors are already affecting the physical, chemical and biological characteristics of freshwater ecosystems.[77] Many of these trends will be exacerbated in the future. Impacts on habitat (loss and transition) and species (range shifts, invasive species interactions, and phenology) are highlighted here.

Habitat loss and transition

Increasing temperatures and associated hydrologic changes are projected to result in significant habitat impacts. Lake levels and river inputs are likely to decline if increases in evapotranspiration (due to higher temperatures, longer growing seasons, and extended ice-free periods) are not offset by an equal or greater increase in precipitation.[78] However, areas that become wetter could have higher lake levels.[79] Where lake levels are permanently lowered, the productive nearshore zone may be degraded as more shoreline is exposed.[80] Habitat for fish that require wetlands for spawning and nursery habitat would be reduced if lake-fringing wetlands become isolated.[81]

Warmer temperatures, reduced snowpack, and altered runoff timing is projected to cause drying of alpine ponds and other wetland habitats, reducing habitat quality for Cascades frog, northwestern salamander, long-toed salamander, garter snakes, and other dependent species.[82] However, loss of snowpack may allow alpine vegetation establishment, leading to improved habitat conditions for some high elevation wildlife species.[83] In the short term, vegetation establishment will be limited to areas favorable to rapid soil development.[84]

A modeling study suggests two-thirds of Alaska will experience a potential biome shift in climate this century, although the rate of change will vary across the landscape.[85] Much of southeast Alaska may be shifting from the North Pacific Maritime biome (dominated by old-growth forests of Sitka spruce, hemlock, and cedar) to the more southerly Canadian Pacific Maritime biome (dominated by yellow and western red cedar, western and mountain hemlock, amabilis and Douglas-fir, Sitka spruce, and alder).[86]

Range shifts, invasive species, and altered phenology

Climate warming is expected to alter the extent of habitat available for cold-, cool-, and warm-water organisms, resulting in range expansions and contractions.[87] Range-restricted species and habitats, particularly polar and mountaintop species and habitats that require cold thermal regimes,[88] show more severe range contractions than other groups and have been the first groups in which whole species have gone extinct due to recent climate change.[89] Amphibians are among the most affected.[90]

The effects of climate change on aquatic organisms may be particularly pronounced in streams where movements are constrained by thermal or structural barriers.[91] Bull trout distribution is strongly associated with temperature,[92] and in the southern end of their range (WA, OR, northwest CA), this coldwater species is generally found at sites where maximum daily temperatures remain below 60.8°F (16°C).[93] However, summer stream temperatures in many bull trout waters at the southern end of their range are projected to exceed 68°F (20°C) by 2100.[94]

Climate change may enhance environmental conditions such that some species are able to survive in new locations, known invasive species expand into new territories, and species that currently are not considered invasive could become invasive, causing significant impacts.[95] Invasive aquatic species that appear to benefit from climate change include hydrilla, Eurasian watermilfoil, white waterlily,[96] and reed canarygrass.[97] In Washington, Oregon, and Idaho, a habitat suitability model projects 21% of the region could support suitable habitat for the invasive tamarisk by 2099 (a two- to ten-fold increase).[98] Tamarisk currently occupies less than 1% of this area, and the remainder is considered highly vulnerable to invasion.[99]

Numerous ecological studies support a general pattern of species' phenological responses to climate change: on average, leaf unfolding, flowering, insect emergence, and the arrival of migratory birds occur earlier than in the past.[100] A significant mean advancement of spring events by 2.3 days per decade has been observed.[101] Studies of phenology from the NPLCC region have found:

- Lamprey run timing shifted 13 days earlier from 1939 to 2007 as Columbia River discharge decreased and water temperatures increased.[102] Migration occurred earliest in warm, low-discharge years and latest in cold, highflow years.[103]
- Populations of Lake Washington's keystone herbivore, *Daphnia*, show long-term statistically significant declines associated with an increasing temporal mismatch with its food source (the spring diatom bloom).[104] In contrast, although the phytoplankton peak advanced by 21 days, the herbivorous rotifer *Keratella* maintained a corresponding phenological response and experienced no apparent decoupling of the predator-prey relationship.[105]

In the future, populations that are most mistimed are generally expected to decline most in number.[106] For fishes dependent on water temperature for spawning cues, the spawning time may shift earlier if river waters begin to warm sooner in the spring.[107] Changes in plankton populations such as those described for *Daphnia* and *Keratella* in Lake Washington may have severe consequences for resource flow to upper trophic levels.[108]

Adaptation to climate change for freshwater aquatic and riparian systems

Given that CO_2 concentrations will continue to increase and exacerbate climate change effects for the foreseeable future,[109] adaptation is emerging as an appropriate response to the unavoidable impacts of climate change.[110] Adaptive actions reduce a system's vulnerability,[111] increase its capacity to withstand or be resilient to change,[112] and/or transform systems to a new state compatible with likely future conditions.[113] Adaptation actions typically reflect three commonly cited tenets: (1) remove other threats and reduce non-climate stressors that exacerbate climate change effects;[114] (2) establish, increase, or adjust protected areas, habitat buffers, and corridors;[115] and, (3) increase monitoring and facilitate management under uncertainty, including scenario-based planning and adaptive management.[116]

Adaptation actions may occur in legal, regulatory, institutional, or decision-making processes, as well as in on-the-ground conservation activities.[117] For example, actions that maintain or increase instream flow can counteract increased stream temperatures, reductions in snowpack, and changes in runoff regimes such as reduced summer stream flows and altered flow timing.[118] Actions to restore or protect wetlands, floodplains, and riparian areas can help moderate or reduce stream temperatures, alleviate the flooding and scouring effects of extreme rainfall or rapid snowmelt, improve habitat quality, and enable species migrations.[119] Decision-makers may also modify or create laws, regulations, and policies to incorporate climate change impacts into infrastructure planning to protect freshwater ecosystems,[120] promote green infrastructure and low impact development approaches to reduce extreme flows and improve water quality and habitat,[121] and adapt Early Detection and Rapid Response protocols to identify, control, or eradicate new and existing invasive species before they reach severe levels.[122]

Although uncertainty and gaps in knowledge exist, sufficient scientific information is available to plan for and address climate change impacts now.[123] Implementing strategic adaptation actions early may reduce severe impacts and prevent the need for more costly actions in the future.[124] To identify and implement adaptation actions, practitioners highlight four broad steps:

1. Assess current and future climate change effects and conduct a vulnerability assessment.[125]
2. Select conservation targets and a course of action that reduce the vulnerabilities and/or climate change effects identified in Step 1.[126]
3. Measure, evaluate, and communicate progress through the design and implementation of monitoring programs.[127]
4. Create an iterative process to reevaluate and revise the plan, policy, or program, including assumptions. [128]

Adaptive approaches to addressing climate change impacts will vary by sector and management goal, across space and time, and by the goals and preferences of those engaged in the process.[129] In all cases, adaptation is not a one-time activity, but is instead a continuous process, constantly evolving as new information is acquired and interim goals are achieved or reassessed.[130] Ultimately, successful climate change adaptation supports a system's capacity to maintain its past or current state in light of climate impacts or transform to a new state amenable to likely future conditions.[131]

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[15] Mantua et al. (2010)
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[20] Pike et al. (2010, Table 19.1, p. 701)
[21] Hamlet and Lettenmaier. (2007, p. 15)
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[24] Allan, Palmer and Poff. (2005, p. 279); Hamlet and Lettenmaier. (2007, p. 16); Martin and Glick. (2008, p. 14); Pike et al. (2010, p. 731); Poff, Brinson and Day. (2002, p. 15)
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LIST OF KEY ACRONYMS AND ABBREVIATIONS

AOGCM	Atmosphere-Ocean General Circulation Model
AR4	4th Assessment Report (produced by IPCC)
BC	Province of British Columbia, Canada
CA	State of California, United States
CIG	Climate Impacts Group
CO_2	Carbon Dioxide
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency, United States
GCM	Global Circulation Model
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
LCC	Landscape Conservation Cooperative
LEK	Local Ecological Knowledge
MoE	Ministry of Environment, British Columbia
NASA	National Aeronautics and Space Administration, United States
NOAA	National Oceanic and Atmospheric Administration, United States
NPLCC	North Pacific Landscape Conservation Cooperative
O_2	Oxygen
OCAR	Oregon Climate Assessment Report (produced by OCCRI)
OCCRI	Oregon Climate Change Research Institute
OR	State of Oregon, United States
PCIC	Pacific Climate Impacts Consortium
PDO	Pacific Decadal Oscillation
PNW	Pacific Northwest
SLR	Sea Level Rise
SRES	Special Report on Emissions Scenarios
SWE	Snow Water Equivalent
TEK	Traditional Ecological Knowledge
WA	State of Washington, United States
WACCIA	Washington Climate Change Impacts Assessment (produced by CIG)

PREFACE

This report is intended as a reference document – a science summary – for the U.S. Fish and Wildlife Service (FWS) Region 1 Science Applications Program. The report compiles findings on climate change impacts and adaptation approaches in freshwater aquatic and riparian ecosystems within the North Pacific Landscape Conservation Cooperative area (NPLCC). The report is intended to make scientific information on climate change impacts within the NPLCC region accessible and useful for natural resources managers and others. It is produced by National Wildlife Federation under a grant from the U.S. FWS (FWS Agreement Number 10170AG200).

This report is a complete "Draft Final" version and represents the fulfillment of Phase One of a two phase project. Under Phase Two, funded through a separate grant, NWF will convene expert focus groups and produce a final report in 2012 that incorporates additional information. A companion "draft final" and final report compiling similar information on marine and coastal ecosystems within the NPLCC area will also be completed under the same timeline.

Production and Methodology

This report draws from peer-reviewed studies, government reports, and publications from non-governmental organizations to summarize climate change and ecological literature on historical baselines, observed trends, future projections, policy and management options, knowledge gaps, and the implications of climate change for species, habitats, and ecosystems in the freshwater environment. Because the report strives to reflect the state of knowledge as represented in the literature, in most cases language is drawn directly from cited sources. By compiling and representing verbatim material from relevant studies rather than attempting to paraphrase or interpret information from these sources, the authors sought to reduce inaccuracies and possible mis-characterizations by presenting data and findings in their original form. The content herein does not, therefore, necessarily reflect the views of National Wildlife Federation or the sponsors of this report. Given the extensive use of verbatim material, in order to improve readability while providing appropriate source attributions, we indicate those passages that reflect verbatim, or near verbatim, material through use of an asterisk (*) as part of the citation footnote. In general, verbatim material is found in the main body of the report, while the Executive Summary, Boxes, and Case Studies generally reflect the report authors' synthesis of multiple sources.

To produce this report, the authors worked with the University of Washington Climate Impacts Group (CIG) and reviewers from federal, state, tribal, non-governmental, and university sectors. CIG provided expert scientific review throughout the production process, as well as assistance in the design and organization of the report. Reviewers provided access to local data and publications, verified the accuracy of content, and helped ensure the report is organized in a way that is relevant and useful for management needs. In addition, we engaged early with stakeholders throughout the NPLCC region for assistance and input in the production of this report. More than 100 people provided input to or review of this document.

Description of Synthesis Documents Utilized

This report draws from primary sources as well as synthesis reports. In synthesis reports, we accepted information as it was presented. Readers are encouraged to refer to the primary sources utilized in those synthesis reports for more information. In most cases, we include the page number for reference. In cases where a primary source is referenced in a secondary source, we have indicated it in the footnote. The global, regional, state, and provincial level synthesis reports drawn from include:

- *Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4): Climate Change 2007.* (2007).
- *Global Climate Change Impacts in the United States.* (2009).
- *Alive and Inseparable: British Columbia's Coastal Environment* (2006).
- *Compendium of forest hydrology and geomorphology in British Columbia: Climate Change Effects on Watershed Processes in British Columbia.* (2010).
- *Environmental Trends in British Columbia: 2007.*
- *Climatic Change*, Volume 102, Numbers 1-2 (September 2010). This volume published the findings of the Washington Climate Change Impacts Assessment (WACCIA).
- *Washington Climate Change Impacts Assessment (WACCIA)* (2009).
- *Oregon Climate Assessment Report (OCAR)* (2010).
- *2009 California Climate Adaptation Strategy: A Report to the Governor of the State of California in Response to Executive Order S-13-2008.*
- *Adapting to Climate Change: A Planning Guide for State Coastal Managers.* (2010).
- *Helping Pacific Salmon Survive the Impact of Climate Change on Freshwater Habitats.* (2007).
- *Preliminary review of adaptation options for climate-sensitive ecosystems and resources.* (2008).
- *Recommendations for a National Wetlands and Climate Change Initiative.* (2009).
- *Strategies for Managing the Effects of Climate Change on Wildlife and Ecosystems.* (2008).
- *The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas.* (2011).

How to Use This Document

Being the first reference document of its kind for the North Pacific LCC region, the extensive details on climate change trends and projections are necessary to provide baseline information on the NPLCC. However, we encourage the reader to focus on the general magnitude and direction of projections, their implications, and on the range of options available to address climate change impacts. It is our hope that this document will provide useful information to North Pacific LCC members and stakeholders, and help facilitate effective conservation that accounts for climate change and its impacts in the region.

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We are grateful to our partner, the University of Washington Climate Impacts Group, for their expertise and insight, and for the many improvements that came through their guidance.

We are indebted to the 100+ individuals who gave generously of their time and knowledge to inform the development of this report. With the expertise of reviewers and interviewees, we were able to acquire and incorporate additional peer-reviewed reports and publications evaluating climate change impacts on relatively small geographic scales. This allowed us to add nuance to the general picture of climate change impacts throughout the NPLCC geography. Further, this report benefitted tremendously from the resources, thoughtfulness, expertise, and suggestions of our 34 reviewers. Thank you for your time and effort throughout the review process. Reviewers and people interviewed are listed in Appendix 6.

We also thank Ashley Quackenbush, Matt Stevenson, and Dan Uthman for GIS support.

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